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INVESTIGATION OF
THE GLOBE PHOTOMETER

BY

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A THESIS SUBMITTED FOR THE
DEGREE OF BACHELOR OF SCIENCE
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FOREWORD.

The globe photometer, or more properly, the Ulbricht integrating sphere is not in itself a photometer. It consists of a hollow globe or sphere, usually of from 18 to 80 inches in diameter, lined with a white material having as nearly as possible a perfectly diffusing surface. Ulbricht demonstrated in 1900 that if a light source be placed in such a globe, the illumination of a small translucent window flush with the globe lining would be proportional to the total light flux emitted by the light source within the globe, provided however that the window were screened from the direct rays by a small opaque screen, and the only rays incident upon the window be those reflected from the entire globe lining. This fact immediately brot this novel integrating device to the attention of photometric engineers, for it is necessary to take but one reading to get the total light flux of the source to be measured, where it is necessary with other devices to take a large number of readings or to rotate the light source. This is not expedient nor accurate for arc lamp photometry on account of the natural variability of arcs. The globe can be used in connection with an ordinary photometer bar or some special photometer. It can be demonstrated* mathematically the the illumination received by the window is a constant, times the total light flux emitted by the light source within the globe. This constant

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* Barrows, Light, Photometry and Illumination, page 166.

is known as the constant of the globe and is readily determined experimentally.

THE UNIVERSITY OF WISCONSIN GLOBE.

The Ulbricht sphere in the photometric laboratories of the University of Wisconsin is 72 inches in diameter and was built in two sections, the division coming on a vertical great circle. It was built in the mechanician's shop at the University and was completed in 1910. Each half of the sphere is built up of sheet iron sections, hammered into shape over a form. The edges are turned and the sections riveted together. At the division of the sphere, the sections are fastened to a steel ring of angle section. Each half of the sphere is supported on a steel cradle, it in turn being mounted on a small truck which rides on a track. The half of the sphere containing the window is made stationary, while the other half may be moved along the track away from it.

At the time of the completion of the sphere, a thesis investigation was made by Messrs. Ballschmider and Schneider to determine the proper lining. Tho they decided that the best material was barium carbonate, due to lack of time and inability to obtain clean barium carbonate, the sphere was finally lined with dental plaster of Paris mixed with water.

The readings at the window, (a translucent glass plate on a horizontal axis of the sphere), have been made by means of a sightbox and standard lamp on an ordinary photometer bar.

INTRODUCTION.

This investigation was undertaken for the purpose of determining and classifying the different factors which affect the accuracy of the results obtained with the globe photometer in the University of Wisconsin laboratories. In general the experimental work consisted in making of a large number of measurements with varying conditions of the factors which were found to affect accuracy. As nearly as possible, all other conditions were kept constant while each factor was varied alone, and the amount of variation noted.

The need for such an investigation has developed since the globe has been put into use. A previous thesis in 1910, was devoted to a consideration of the globe lining almost entirely. The globe was lined and put into use too late that year for extended investigation as to its accuracy. Since then it has been noted, in using the globe, that the conatant at various times has varied as much as ten percent, when no attention was paid to exact duplication of conditions. Since there have been no standard specifications nor detailed instructions for use of the globe, this variation might be due to one or several causes. It was desired to ascertain the exact causes of variations and the amount of variation due to each.

In the literature upon the globe photometer there

seems to be an almost total lack of experimental data about inaccuracies to be expected. All authors agree as to the theoretical correctness of the globe's indications, but they differ to a marked degree in such matters as the placing of the lamp in the globe and the size and position of the screen. No experimental has come to hand concerning the above factors and other similar ones, so the authors hope this thesis may be contributive.

The general character of the work has been to develope the nature and amount of inaccuracies, and to prepare a set of specifications for the use of the University of Wisconsin globe which would make possible the accurate duplication of results by different experimenters and at different times.

GENERAL OUTLINE OF INVESTIGATION.

The general method of the investigation undertaken by the authors will be outlined here and a detailed discussion of the work will follow. First the effect of the opening at the juncture of the two halves of the globe was investigated. In moving the globe to its present location it became sprung, so that the two halves do not meet perfectly. There is a crack averaging about one-eighth of an inch in width all around the juncture of the two halves, thru which some light leaks out into the photometer room. The effect of this leakage was determined by taking readings at the window with different openings,and finally by closing the crack with plaster of paris. The effect of the position of the lamp within the globe was determined by a number of vertical and horizontal traverses with readings at frequent intervals. The effect of different sizes of screens and of different distances of screens from the light source was obtained by screen traverses with several sizes of screens,with the light source at the center of the globe. In order to determine whether the globe gave a theoretically correct indication,no matter what the distribution curve of the light source,a lamp was equipped with a focusing reflector and readings taken with the light directed toward several different parts of the sphere. At this time certain discrepancies were noticed in similar

readings taken on different days, and the effect of dust on the globe lining and on the window was determined by brushing out portions of the globe and noting the effect on the indications at the window. Certain variations in readings with lights having the same intensity but different distribution curves made it desirable to ascertain whether the globe lining was sufficiently good as a diffuse reflector. Test plates were made up of the same material and readings taken to see if the reflection followed Lambert's cosine law. The lining was found to be very good so a large number of readings were taken with different incandescent lamps of known candle-power, placed in a position and used with a certain screen, in accordance with specifications prepared on the basis of the investigation that had been made. From these readings and from the known spherical candle-powers of the lamps used, the globe constant was determined for each. Tests were made for a few arc lamps to test the efficacy and adaptibility of the standard specifications prepared by the authors. The early part of the investigation was carried out with a Sharp-Millar photometer at the window opening, and consistent results were obtained, though only comparative data was aimed at. Hence there is no definite correspondence between the different tables of data. Later, attempt was made to use a sight-box on an ordinary photometer bar and photometer the globe window. Extraneous light and low illumination values made this method very inaccurate so there was constructed an enclosed bar using

a Lummer-Brodhun sight-box,which gave excellent results. Thruout the investigation ten or more readings were taken at each setting and position to insure the highest possible accuracy. Each reading recorded in the data or used in computing constants and plotting curves is the average of at least ten photometer settings. Since comparative results only were desired for most part,the personal equation was eliminated by having only one observer take all readings to be compared.

DETAILED DESCRIPTION OF EXPERIMENTATION WITH DISCUSSION OF DATA AND RESULTS.

In this portion of the thesis the details of the different points of investigation brot out in the above outlined discussion are given,together with descriptions of the apparatus and appliances used,with the reasons therefor. The tabulated data here given is discussed and deductions drawn therefrom which show the reasons for the various requirements given in the final specifications for the use of this particular globe. The investigation has been perfectly general in nature and the conclusions drawn may apply to any similar globe.

At the start it was decided to use circular white mat blotting paper screens within the globe to keep direct rays from the window,and to work with lamps large enough to give sufficient intensity at the photometer screen for accurate balances. In all cases the average of at least ten settings was taken for each recorded reading. These ten readings all agreed within about two percent of their mean. If any reading fell outside this limit it was thrown out. This happened but seldom,perhaps once in thirty readings and was due to optical fatigue on the part of the observer or to some accidental cause.

Owing to the difficulty of readily and tightly clos-

ing the crack at the juncture of the two halves of the globe, to determine the effect of the minimum light leakage it was decided to try the effect of different openings on indications at the window, following the method of Hoeveler in a similar private investigation, the results of which are to be found in the records of the University electrical laboratories. The results obtained, shown in TABLE I, when reduced to a curve, agree almost exactly with those of Hoveler, though his results were not plotted until comparison was desired in connection with this thesis.

TABLE I.

In. Opening.	7.90	6.35	5.03	3.97	3.00	2.12	1.22	0.51	0.12
Reading.	4.00	4.50	5.12	5.90	6.80	7.18	8.15	9.10	9.60

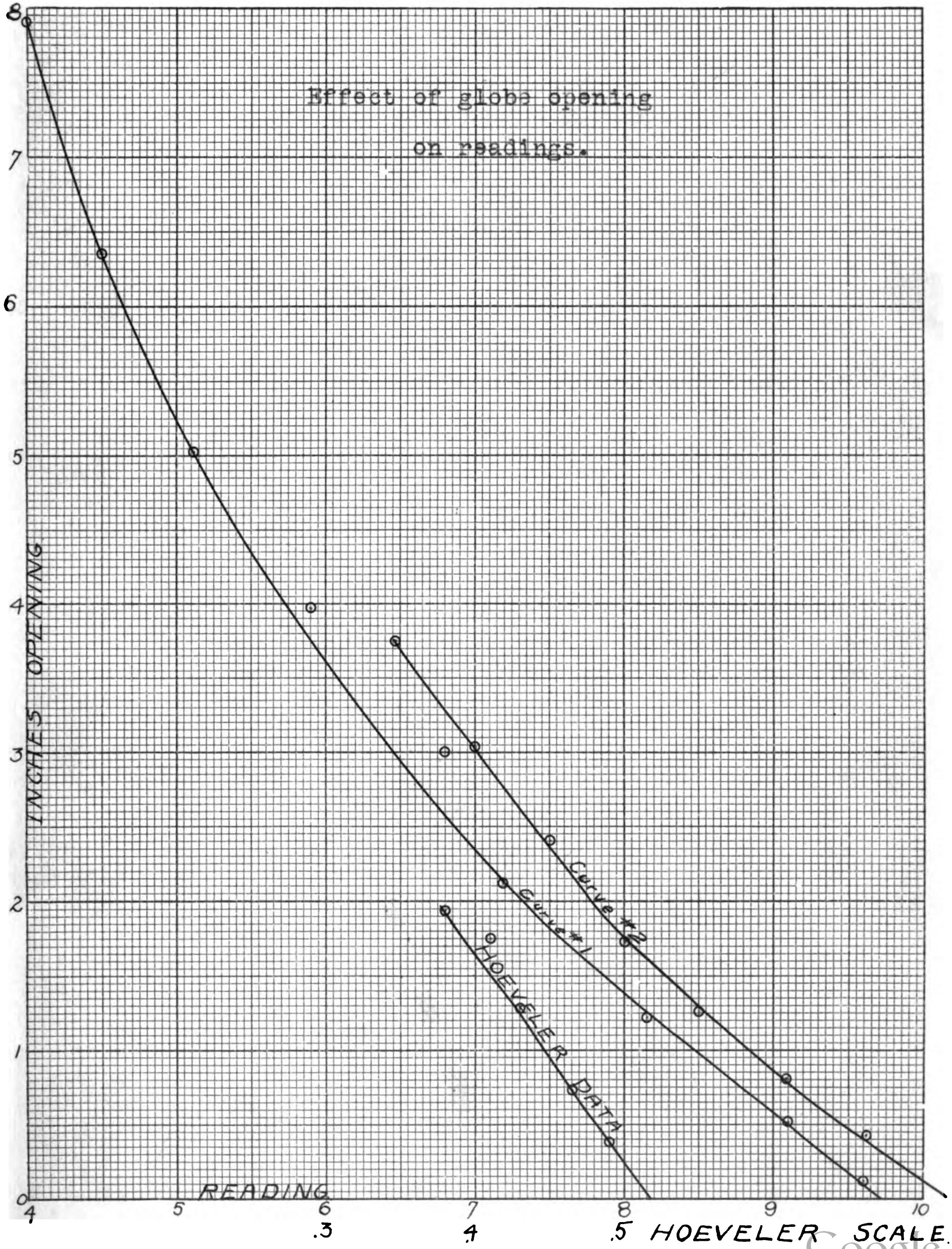
In. Opening.	3.75	3.03	2.40	1.73	1.26	0.79	0.43	0.17
Reading.	6.47	7.00	7.50	8.00	8.50	9.07	9.62	9.70

HOVELER DATA.

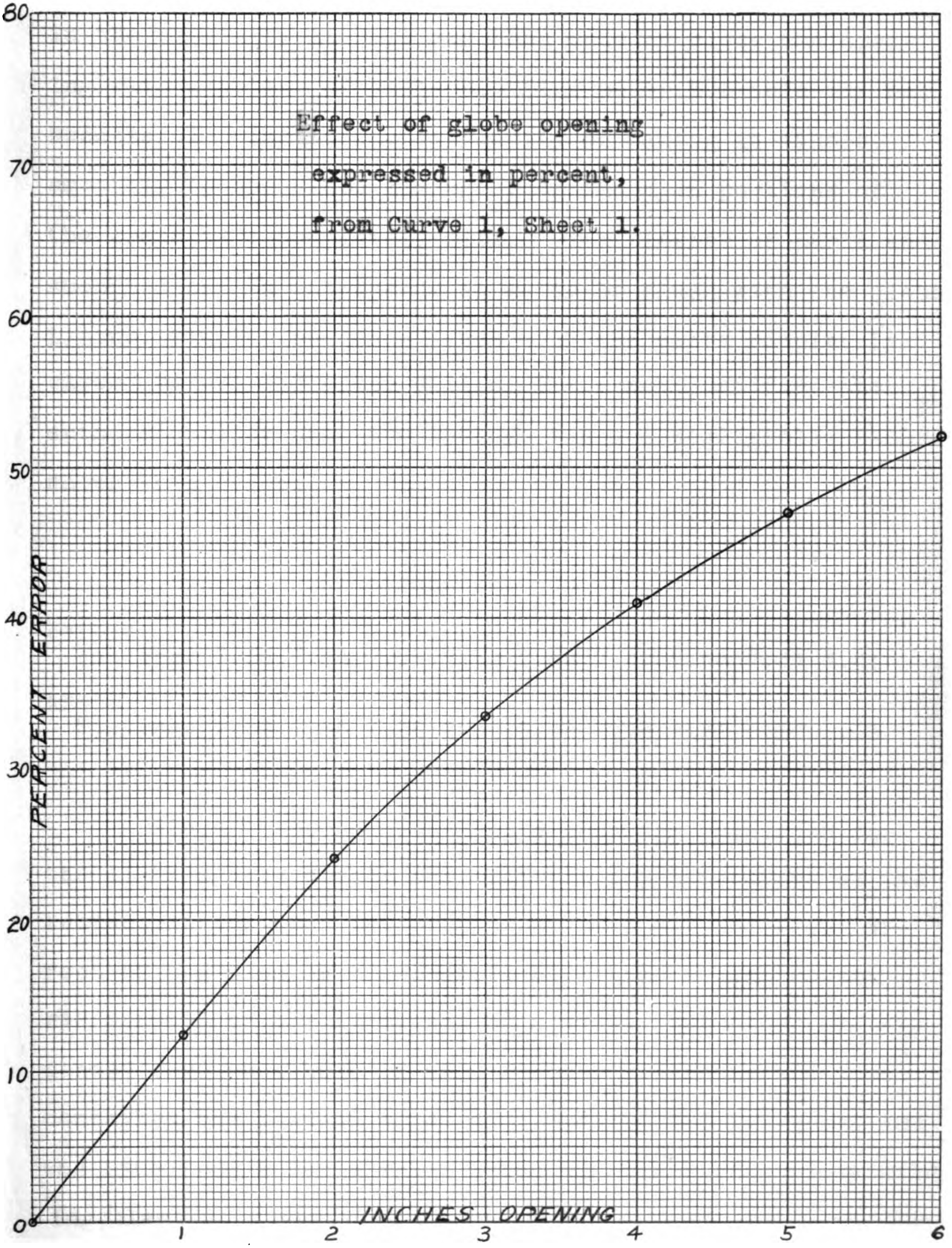
In. Opening.	1.94	1.75	1.28	0.72	0.37
Reading.	.38	.41	.43	.47	.49

Hoveler concluded that the effect of the crack was negligable, from the fact that a certain definite variation of the opening made a negligable difference in the readings. However it was noticed that if the curves of SHEET I be exterpolated to the zero opening abscissathe difference between the minimum possible opening and the zero opening

CURVE SHEET I.



CURVE SHEET I, A.



would make as much as two and one half percent difference in the readings. Attempt was then made to close the opening with a collar of white blotting paper,but this was not successful owing to the difficulty of making it adhere smoothly to the globe lining. Then the open portions of the crack were completely filled with plaster of paris and smoothed off on the inside so as to be flush with the globe lining. Similar readings taken with the globe completely closed before and after filling the crack justified the authors' belief that the leakage was not negligible. TABLE II shows this effect.

TABLE II.

Before Filling.	7.26	7.34	7.44	7.40	7.36	7.42	7.36	7.47	7.51
After Filling.	7.54	7.65	7.58	7.66	7.63	7.74	7.79	8.10	8.03

Since there is no definite position specified for the light source within the globe in any literature on the subject,it was thot interesting to find out the exact effect of position on readings. Accordingly a lamp socket was mounted on the lower end of a metal tube which was suspended through a hole in the top of the globe. This tube contained the lead-in wires and leads to the voltmeter and was hung from a cable which extended over pulleys to a sliding clamp at a vertical scale on the wall of the room. The

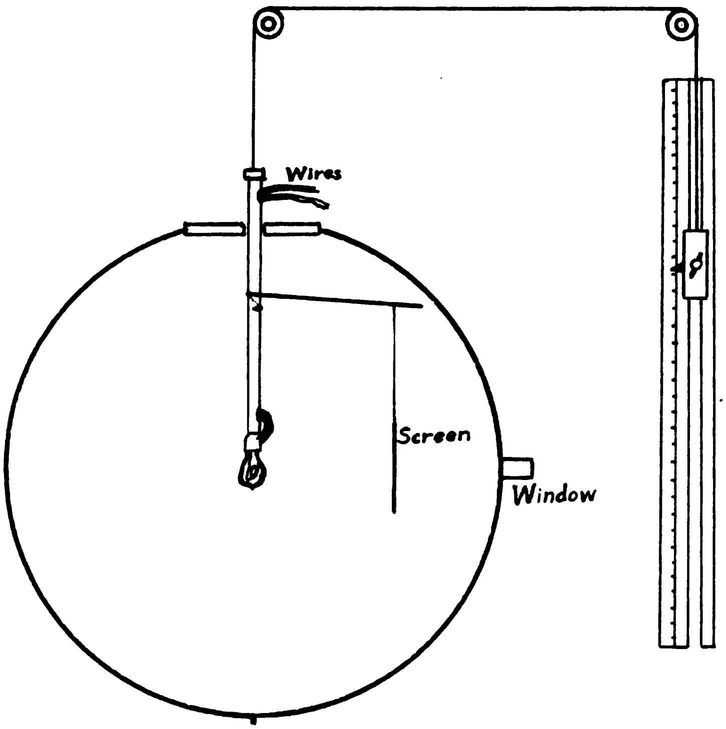


FIGURE I.

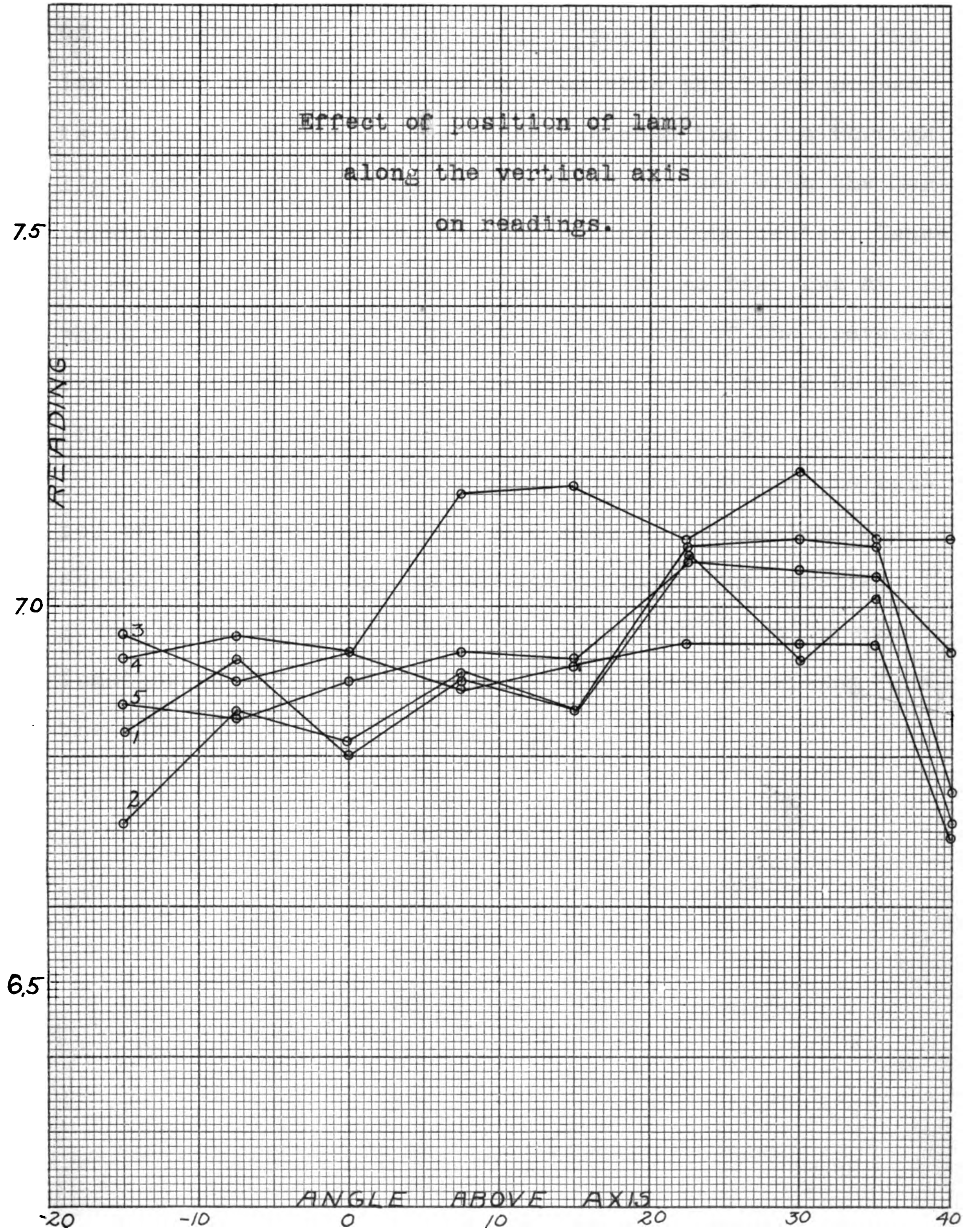
arrangement is shown in FIG.I. By the use of this device the position of the lamp on the vertical axis of the globe could be changed and could be read on a scale without opening the globe. The results of several such traverses are given in TABLE III.

TABLE III.

Angle above Horizontal Axis.	Inches Distance above.	#1.	#2.	#3.	#4.	#5.
40	30	6.76	6.71	7.09	6.69	6.94
35	25	7.08	7.01	7.09	6.95	7.04
30	20.5	7.09	6.93	7.18	6.95	7.05
22.5	14.7	7.08	7.07	7.09	6.95	7.06
15	9.5	6.86	6.86	7.16	6.92	6.93
7.5	4.7	6.90	6.91	7.15	6.89	6.94
0	0	6.80	6.82	6.94	6.94	6.90
-7.5	-4.7	6.93	6.86	6.90	6.96	6.85
-15	-9.5	6.84	6.71	6.96	6.93	6.87

Curves plotted from these traverses are shown on SHEET II. It will be noted that the minimum reading in each case is when the lamp and screen are at the zero position, or at the center of the globe. This is to be expected,for it is then that the screen is directly in front of the window and is cutting off from it the greatest amount of light,the normal radiation or first reflection from the back of the globe. As the screen and light are moved above and below the zero position,the apparent area of the screen

CURVE SHEET II.



decreases and it at the same time moves away from the path of the normal rays from directly opposite the window. The indication seems to reach a maximum when the light source is at the 30 degree position, that is, when the line through light and window makes an angle of 30 degrees with the horizontal line through the window and the globe center. Hence it seems that the 30 degree position is the best one at which to operate the globe, for the maximum of the traverse curve is at this point and the minimun error would be introduced for a slight variation on either side.

Horizontal traverses along an axis through the center of the globe and window were made by moving lamp and screen together along the horizontal axis. The results, given in TABLE IV, show that the indication is an inverse function of the apparent size of the screen as viewed from the window.

TABLE IV.

	Inches From Center.	Reading.
	25	6.01
	20	6.53
Toward Window.	15	6.69
	10	6.83
	5	6.86
	0	7.07

TABLE IV CONT'D.

From Window.	5	6.99
	10	6.98
	15	7.05
	20	6.98
	25	7.04
	30	6.87

This data is of little value in practical working of the photometer except as showing the general effect of size and position of screens.

Tests for the effect of the size and position of screens were made with the lamp at the center of the globe. A small wooden rod painted white was suspended in the globe some ten inches above and parallel to the horizontal axis through the window. Different sized screens were hung from this rod at the proper height and moved to different distances from the lamp. Readings were taken at several positions of each screen. These readings are given in TABLE V.

TABLE V.

Distance from Lamp, Inches.	5	10	15	20	25	30
Dia. of Screen						
4	7.29	7.62	7.45	7.48	7.37	7.10
8	7.15	7.31	7.22	7.15	7.13	6.64
12	6.96	7.15	7.15	7.07	6.70	

TABLE V CONT'D.

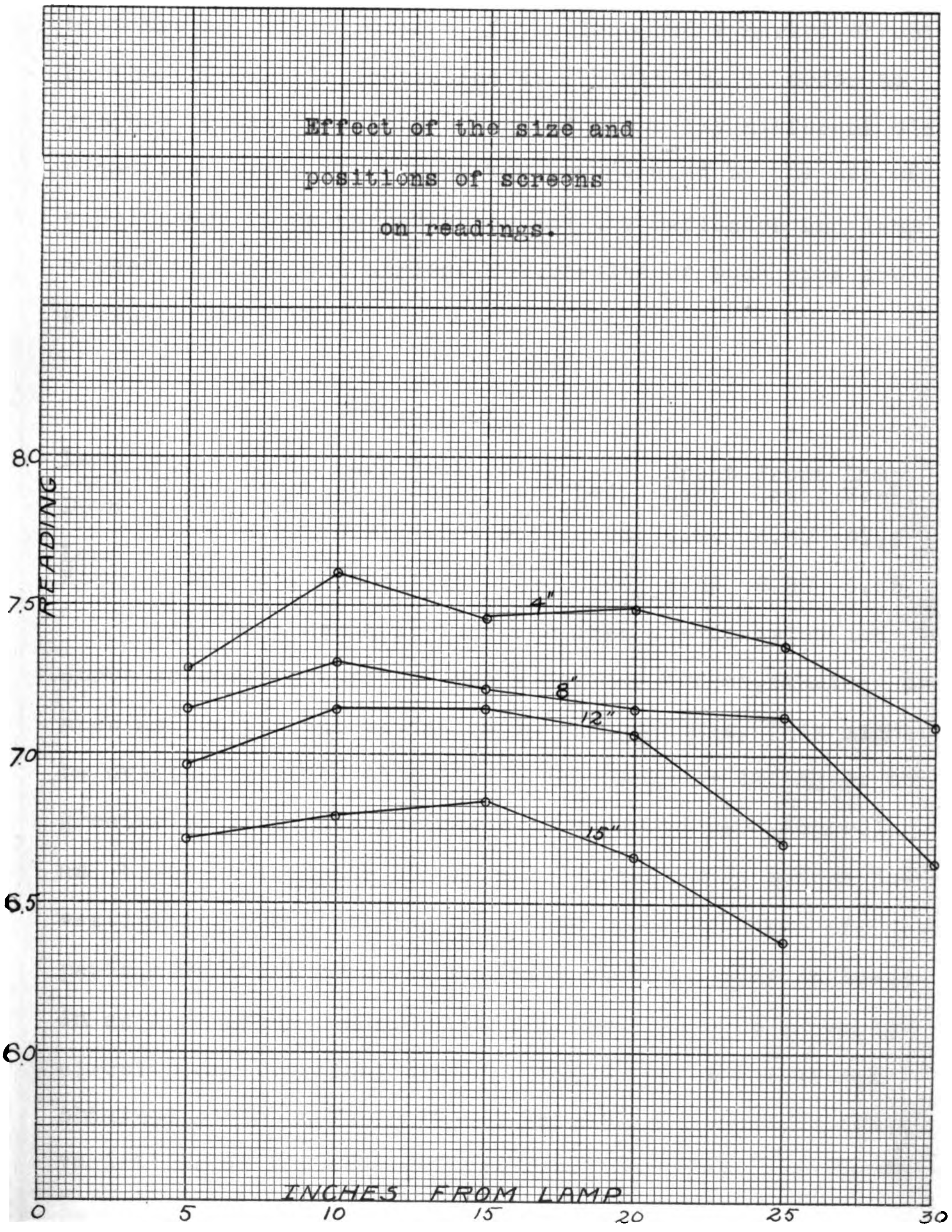
15	6.71	6.79	6.84	6.65	6.37

The curves on SHEET III show the effect of the size and position of the screen graphically. The curves show that the larger the screen the less the indication, but the rate of change seems to be less for certain screens at certain distances. For instance, the indication with a 12 inch screen at 15 inches from the lamp changes least rapidly for any variation of size or position of screen. It would seem then that it would be well to choose some such values as the above as standard. Data for vertical traverses with three different sized screens, before and after the crack was closed, are given in TABLE VI. These data bear out former data as to the effect of the crack, position of the lamp and size of screen.

TABLE VI.

Angle	4" Screen		6" Screen		10" Screen	
	Before.	After.	Before.	After	Before.	After.
35	7.89	7.93	7.51	7.60	7.20	7.32
30	7.68	7.88	7.47	7.61	7.20	7.30
22.5	7.72	7.86	7.36	7.55	7.10	7.24
15	7.62	7.73	7.42	7.44	7.04	7.15
7.5	7.59	7.78	7.36	7.42	6.99	7.15
0	7.52	7.72	7.40	7.36	6.97	7.10
-7.5	7.59	7.68	7.44	7.27	6.98	7.07
-15	7.50	7.66	7.34	7.26	6.89	7.00

CURVE SHEET III.



It was noticed in the data on the vertical traverses that the angular direction of the lamp had a marked effect on the photometric indication at the window. In order to further investigate this effect of virtually different distribution curves, the effect was exaggerated by the use of a Holophane focusing reflector and the reflector and lamp turned to different angles. The results of such runs are shown in TABLE VII.

TABLE VII.

	Front Right	Right	Back Rt.	Back Cent.	Back Left	Left	Front Left	Front Cent.	Lamp Vert.
Lamp 45° Down	6.65	6.73	6.91	6.80	6.79	6.92	6.64	6.60	6.96
Lamp Hor.	6.47	6.71	6.66	6.55	6.60	6.64	6.49	6.20	6.65

The data seems to indicate that the distribution curve of the light source has a decided effect, causing as much as ten percent variation in the readings. This might be due to imperfect diffusion from the globe lining or to greater or less interference by the screen used, according as it was in the path of the more direct rays. Before investigating the diffusing qualities of the plaster of paris, a vertical traverse was made with the lamp enclosed in an ALBA sphere in order to get the effect of a nearly circular, mean vertical distribution curve. The readings obtained, given in TABLE VIII, show the same characteristic variations as the vertical traverses in TABLE III. It was

concluded that what effect was due to radically different distribution curves would have to be taken into account by specifications,but the ordinary differences found in incandescent lamps and translucent globe shades were negligible.

TABLE VIII.

Angle above horizontal	0°	10°	20°	30°
Reading	10.50	10.59	10.57	10.67

All through the investigation up to this point, it was noticed that similar conditions gave differences of as much as 5 % on different days. Investigation showed that this was due to an almost imperceptible coating of dust which would gather on the globe lining and on the window. Accordingly the globe was allowed to stand tightly closed for a few days at different times and a reading taken before any attempt was made to clean the lining. Then the lining was brushed with a stiff brush, the dust allowed to settle, and a second reading taken. A thorough second brushing was sufficient to bring the indication up to practically what it was with a clean globe on the previous day, as shown in TABLE IX. Much depends on the thoroughness of the second brushing and on allowing all dust to settle and then carefully dusting off window, lamp and shade. The use of a stiff brush on the plaster of Paris lining necessarily brings out

some of the plaster with the dust every time the globe is brushed out before use. It would seem that this would tend appreciably to thin the lining. However the amount of material removed in this way does not exceed a cubic inch for perhaps ten brushings. It will be seen that this amount is very nearly negligible when it is considered that it comes from half the surface of a 72 inch sphere.

TABLE IX.

Original reading	Without brushing	First brushing	Second brushing	Window dusted
	6.21	6.34	6.29	6.43
	17.27		17.4	
	16.4		16.55	
11.8	11.14	11.3	11.76	
7.91	7.72	7.99	8.01	

Reference to a rather extended consideration of the reflecting qualities of globe lining materials in a previous thesis* failed to bring forth any data on the plaster of Paris with which the globe was lined. Several test plates were accordingly constructed of this plaster and curves obtained from them in the same wa the test plates were tried out in the previous thesis. The plate under test was covered with black mat paper having a 25 cm. circular opening and supported vertically. The Sharp-Millar photometer

* loc. cit.

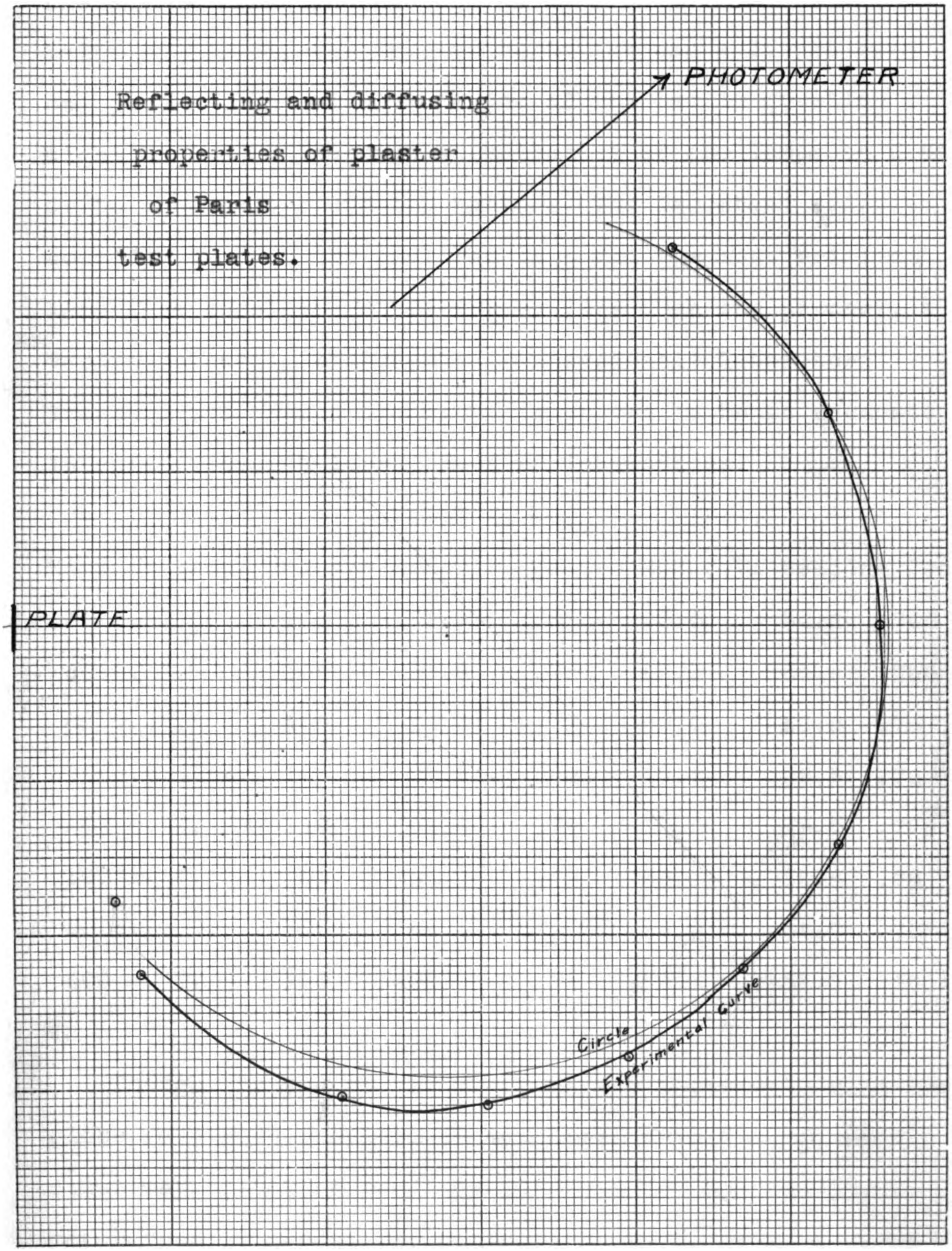
was mounted on a level with the center of the plate with its screen perpendicular to a line making an angle of 45° with the plate surface. A lamp mounted on an arm revolving horizontally about the center of the test plate provided illumination on the plate. Readings were taken of light received at the photometer for several different positions of the lamp. Since the angle between the plate and the path of the rays to the photometer is constant, the relative intensities of the reflected light energy from the plate was read directly. This should be proportional to the cosine of the angle between a perpendicular to the surface of the plate and the path of the incident rays, if the material follows Lambert's cosine law. A polar curve plotted from the data obtained should be approximately a circle. The data are given in TABLE X, and one curve is plotted on CURVE SHEET IV with the corresponding cosine circle, to show how much this plaster surface varies from a perfectly diffusing one. Three runs were made with three different finishes, scraped, rough sandpapered and smooth sandpapered. The readings corresponded so closely as to warrant the conclusion that there was no appreciable difference in the finishes for this purpose. The results of this test on the plaster of Paris indicate that the present globe lining could hardly be improved upon as a diffusing surface.

TABLE X.

Angle from plate.	Surface finish. Scraped	Rough sand	Smooth sand
20	2.36	2.41	2.36
35	3.67	3.67	3.69
45	4.39	4.41	4.31
55	4.84	4.81	4.81
65	5.20	5.15	5.19
75	5.43	5.24	5.47
90	5.57	5.53	5.56
105	5.39	5.32	5.34
120	4.93	4.95	4.88

Several lamps were selected and their mean horizontal candle powers measured on a photometer bar against a certified standard lamp. From these, by means of spherical reduction factors, the mean spherical candle powers were calculated. A few were checked out by making a distribution curve run and using a Rousseau diagram. With lamp 30° above the central position, and using a 12 inch screen, 16 inches from the axis of suspension, a reading for each of these lamps was taken and incorporated in TABLE XI. From these readings and from the known mean spherical candle powers of the lamps, several independent determinations of the globe constant were made. The maximum variation of these constants was about 4 % when readings were taken with

CURVE SHEET IV.



the Sharp-Millar photometer. Aside from two of the eight lamps so tested, the maximum variation was a little over one percent. The wide variation of the two in question might be due to inaccurate photometry of the lamps on a bar or to incorrect reduction factors. The important point to consider is that the smallest lamp and the most brilliant lamp gave constants differing by less than one percent, a variation easily chargeable to unavoidable laboratory inaccuracies. Hence the globe is proven to be an accurate integrator over a large range of intensities.

TABLE XI.

Kind of lamp	Voltage	M.H.C.P.	Factor	M.S.C.P.	Reading	Const.
32 c.p. C.	105	30.9	.825	25.5	34.2	.745
60 w. T.	106	53.9	.78	42.1	55.8	.755
60 w. T.	106	55.06	.78	43.0	56.6	.76
16 c.p. Gem.	106	23.5	.825	19.4	25.5	.76
100 w. T.	110	93.4	.78	72.8	93.5	.778
100 w. T.	100	64.4	.78	50.2	65.8	.76
50 c.p. C.	105	48.1	Rousseau diagram	41.8	54.7	.763
500 w. T.	110	409.0	.81	332.0	431.0	.765

Though the use of the Sharp-Millar photometer with the globe gave good results, it was desired to arrange some other way of taking readings in order to have the photometer free if needed for other work. Accordingly a sight

box and a standard lamp were mounted on a 300 cm. bar in line with the globe window and photometric measurements made with several lamps in the globe, as before. TABLE XII gives the results obtained by these measurements. The

TABLE XII.

Kind of lamp	Voltage	M.S.C.P.	Reading	Globe const.
32 c.p. C.	105	25.5	.0627	407
60 w. T.	106	42.1	.0957	440
60 w. T.	106	43.0	.0975	441
100 w. T.	110	72.8	.166	439
100 w. T.	100	50.2	.1178	425
50 c.p. C.	105	41.8	.0918	455
500 w. T.	110	332.0	.668	497

different values of the globe constant vary by 20 %, or by 7 % when the two extreme readings out of six are thrown out. The wide variation when this method is used may be charged to low illumination values at the sight box and to the influence of extraneous light from the room on the photometer screen. Though higher illumination might remedy the effect, it was found impossible to attain it because of the low transmission coefficient of the glass of the globe window. It was found impossible to obtain suitable translucent glass for this purpose which had higher transmission coefficient than about six percent.

In order to bring up the illumination on the photometer screen and to shut out extraneous light, the authors constructed a short enclosed photometer,having a Lummer-Brodhun sight box in a fixed position near the globe window and a small movable two volt lamp as the standard. The arrangement was very similar to that in the Sharp-Millar portable photometer. Measurements of a large number of lamps of known light flux were made with this apparatus and values of globe constants computed as before. A very wide variation, shown in TABLE XIII, indicated that there was something radically wrong with the apparatus, for it was not at all difficult to obtain most accurate balances, and the lamps had all been verified by other means. Investigation showed the the black lining of the photometer box had a glossy surface. At this time the breakage of the sight box cube forced the use of the Sharp-Millar instrument again. Relining of the photometer box with a dead black surface and the use of a series of screens between lamp and sight box would, it is thought, eliminate the large errors noticed and make for the most accurate determinations.

TABLE XIII.

Kind of lamp	Voltage	M.S.C.P.	Reading	Globe Const.
100 w. T.	110	76.	11.76	6.46
100 w. T.	110	74.	11.38	6.5
100 w. T.	110	75.4	11.88	6.34
100 w. T.	110	70.	10.31	6.79
100 w. T.	110	74.4	11.56	6.4
100 w. T.	110	66.	10.10	5.93
32 c.p. C.	105	25.5	3.25	7.85
60 w. T.	106	43.	5.82	7.4
16 c.p. Gem.	106	19.4	2.078	9.34
60 w. T.	106	42.1	6.0	7.02
50 c.p. C.	105	41.8	5.94	7.05
100 w. T.	110	72.8	10.86	6.73
100 w. T.	100	50.2	7.97	6.3

Since the globe is especially adaptable to arc lamp photometry by reason of its peculiar instantaneous integrating property, it was thought desirable to try a few arc and large incandescent lamps in it. Owing to the limited size of the globe it is impossible to mount arc lamps in the usual 30° position, so the central position was decided upon. The large dark surfaces of the arc lamps would absorb much incident light and reduce the intensity at the window and increase the globe constant. Therefore the constant must be determined by means of a standard lamp,

with the arc lamp in place, to take account of absorbtion. The most convenient way to mount the incandescent lamp for such work is to support it from the bottom of the globe, 30° below the center. Test showed that this gave the same window reading that the 30° above center position did. The method followed in testing large lamps was to mount standard lamp 30° below center, and the large lamp with the light source at center, with 12 inch screens between each and the window. The standard was turned on and ten readings taken to determine the constant. The standard was turned off and the arc lamp turned on and ten readings rapidly taken. The average of these was multiplied by the constant obtained above, and the result was the mean spherical candle power of the large lamp. TABLE XIV, shows the results

TABLE XIV.

Reading of 72.8 M.S.C.P. std.	Globe const.	Type of lamp	Reading	M.S.C.P.
3.42	21.3	D.C. arc	6.25	133
2.42	30.1	Magnetite arc	9.41	283
2.607	27.9	Flaming arc.	9.34	260
3.475	21.	500 watt T.	15.33	322

of tests on three different kinds of arc lamps and a 500 watt tungsten incandescent lamp. It is of interest to note that the M.S.C.P. of the tungsten lamp thus obtained is within 2.5 % of its actual value, as determined from other measurements on a photometer bar and the use of reduction

factors furnished by the Government. The error may be accounted for by the fact that two such large screens were used and by error in calibration of the standard. However the actual individual readings, shown in TABLE XV, vary widely in the case of th arc lamps because of flickering and pumping, and the accuracy obtained, even at 2.5 %, is sufficient.

TABLE XV.

	Arc lamps			500 watt
	Carbon	Magnetite	Flaming	tungsten lamp
	7.5	10.0	8.2	15.3
	7.4	9.2	8.7	15.2
	6.7	9.5	8.8	15.3
	6.4	9.4	8.6	15.4
	6.2	8.8	10.0	15.5
	5.6	9.0	9.0	15.5
	6.5	10.0	9.0	15.3
	5.0	9.0	10.5	15.4
	4.5	8.8	9.6	15.4
	6.2	9.4	11.0	15.5
Mean	6.25	9.41	9.34	15.33

The carbon arc used was rated at 110 volts and 4.5 amperes, multiple. The magnetite arc was a 4 ampere, 110 volt lamp. The flaming arc was a 10 ampere, 110 volt lamp, imported from Germany. It is rated as burning 17 hours. It was purchased from Felix Hamburg. The tungsten lamp was rated at 500 watts at 110 volts. All were burned on d.c. in these tests.

CONCLUSIONS.

When conditions are identical for different light sources within the globe photometer, indications within one and one-half percent of correct may be expected for incandescent lamp photometry. The large errors that may creep in because of impossibility of keeping globe lining, the screen and the window free from dust for a protracted period makes it imperative that great care be exercised to eliminate such errors by frequent brushing of the globe, and by frequent redetermination of the globe constant. It has been found that the operation of a ventilating fan in ordinary weather, or the natural ventilation in dusty weather will carry enough dust into the globe in an hour to affect readings noticeably, even if it be closed most of the time. For use of the University of Wisconsin globe, it has been thought best to prepare a set of formal specifications embodying the variables which affect the globe accuracy and showing what error may be introduced by definite variation of each. In this way it will be possible for different future experimenters to know just how important each variable factor is and what care they must take to reproduce conditions exactly. Attempt has been made to make the specifications, which follow, perfectly definite, and yet to make them of general value in connection with any globe photometer.

SPECIFICATIONS FOR USE OF
THE GLOBE PHOTOMETER.

For incandescent lamp photometry, light source shall be suspended in the vertical axis of the globe with its center in such a position above the center of the globe that a line through the center of the light source and the center of the window shall make an angle of 30° with the horizontal.

A 12 inch, circular, white, blotting paper screen shall be interposed between the light source and the window so that its center shall be in line with the centers of the light source and the window. This screen shall be hung vertically, 16 inches from the vertical axis of the globe.

The interior surface of the globe shall be thoroughly brushed out before using and the dust allowed to settle. Repeated brushings shall be given till all visible dust is removed. The window and lamp and screen shall then be dusted off.

For arc lamp photometry, the arc lamp shall be hung so that the light source shall be at the center of the globe. The standard lamp used in connection shall be supported tip upward, directly below the arc lamp, 30° below the horizontal. A 12 inch screen shall be interposed between arc lamp and window, 16 inches from the lamp center, and a 6 inch screen directly below it between the standard

lamp and the window.

Voltmeter leads shall be brought out from as near the lamps as possible. Wires, sockets, supports, etc. used inside the globe shall be as small as possible and white in color. Imperfections in globe lining and jointing shall be repaired with plaster of Paris as they occur.

From data and curves given in this thesis the following figures on expected variations are derived: Curves on SHEET II show that a variation of the height of the light source from specified positions by 5 inches would not make an error greater than one percent. Curves on SHEET III show that an increase in diameter of the screen by one inch would decrease readings by not more than 1.5 percent. Likewise decrease in diameter of the screen one inch would increase readings by not more than 0.7 percent. The same set of curves shows that variation of the distance of the screen from the vertical axis by one inch would make an error of not over 0.2 percent. Inadequate cleaning of the globe might reduce readings by as much as 5.5 percent, as shown in TABLE IX.

Globe constants should be redetermined each day for incandescent lamp photometry, and for each lamp for arc lamp photometry, if the best possible results are to be obtained. At least ten readings should be taken of each lamp.

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